EFFECTIVE DISPERSION OF GRAPHENE NANOPLATELETS IN EPOXY GROUT FOR STRUCTURAL REHABILITATION

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I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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DEDICATION

To my beloved parent,

Mr. Kasmaon Darusman and Mdm. Laili bt Othman.

Thank you for your unconditional love and support!

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ABSTRAK

Saluran paip bawah tanah adalah cara paling selamat untuk mengangkut minyak dan gas. Pada masa kini, banyak teknik pemulihan dan kaedah pembaikan boleh didapati untuk membaiki saluran paip di darat dan luar pesisir pantai termasuk penggunaan komposit polimer diperkuat gential (*FRP)*. Sistem pembaikan komposit yang melibatkan tiga bahagian iaitu pembungkus komposit, pelekat dan bahan *infill* adalah teknik yang paling disukai untuk membaiki saluran paip yang rosak dalam industri minyak dan gas. Kekuatan bahan *infill* yang tinggi mempunyai potensi untuk meningkatkan prestasi pembaikan secara keseluruhan. Tujuan penyelidikan ini adalah untuk mengkaji keberkesanan penyebaran *graphene nanoplatelets* sebagai penguatan untuk meningkatkan prestasi bahan epoksi sebagai *infill*. Dengan menambahkan 0.01%, 0.05% dan 0.1% *graphene nanoplatelets* ke dalam epoksi, penyebaran telah dilakukan dengan menggunakan mesin *three-roll mill* di mana graphene adalah diuraikan untuk mencapai penyebaran yang sekata. Ujian sifat mekanikal telah dijalankan mengikut ASTM D638 untuk ujian tegangan dan ASTM D695 untuk ujian mampatan. Keputusan ujian tegangan dan mampatan menunjukkan peningkatan kekuatan untuk semua sampel yang diubah suai. Kekuatan tegangan tertinggi dicatatkan pada 20.89MPa untuk sampel dengan 0.1% graphena dan 82.67MPa untuk sampel ditambah 0.05% graphena untuk kekuatan mampatan. Peningkatan kekuatan yang dicatatkan adalah antara 46% hingga 88% dan 3% kepada 16% di bawah ujian tegangan dan mampatan. Oleh itu, berdasarkan penemuan kajian ini, graphene menunjukkan keupayaan untuk meningkatkan prestasi ujian tegangan dan pemampatan berbanding dengan sampel kawalan.

ABSTRACT

Underground pipeline is the safest ways to transport oil and gas. Nowadays, a lot of rehabilitation techniques and repair methods are available for onshore and offshore pipelines including the usage of Fibre-Reinforced Polymer composite. Composite repair systems involving three parts which are composite wrapper, adhesive and infill materials is most preferable techniques used for repairing damaged pipeline in oil and gas industry. High strength infill materials has the potential in improving overall repair performance. The purpose of this research is to investigate the effectiveness dispersion of graphene nanoplatelets as reinforcement to enhance the performance of epoxy grout as infill materials. By adding 0.01%, 0.05% and 0.1% of graphene nanoplatelets, the dispersion was done using a three-roll mill machine where the graphene was de-agglomerate to achieve homogenous dispersion. The mechanical properties tests were carried out in accordance to the ASTM D638 for tensile test and ASTM D695 for compressive test. The results of tensile and compression tests show increment of strength for all modified samples. The highest tensile strength was recorded at 20.89MPa for sample with 0.1% graphene and 82.67MPa for sample added 0.05% graphene for compressive strength. The strength increment was recoded range from 46% to 88% and 3% to 16% under tensile and compression test, respectively. Thus, based on the findings, graphene nanoplatelets shows the ability to improve performance for tensile and compressive properties as compared to control sample.

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LIST OF SYMBOLS

km	kilometre
m/s	Metre per second
µm	Micro metre
rpm	Rotational per minute
mm	Milli metre
%	percentage
±	Plus minus
mm/min	Milli metre per minute
$\bar{x}$	Mean
n	Total numbers
s	Standard deviation
$\sum x_i$	Summation of value
MPa	Mega pascal
GPa	Giga pascal
N/mm^2	Newton per milli metre square

LIST OF ABBREVIATIONS

MAOP	Maximum Allowable Operating Pressure
FESEM	Field Emission Scanning Electron Microscope
SOP	Standing Operating Procedure
ASME	The American Society of Mechanical Engineer
ISO	International Organization for Standardization
FRP	Fibre Reinforced Polymer
SWNT	Single-Walled Carbon Nanotube
CN	Cyanoacrylate
UTM	Universal Testing Machine
GnP	Graphene nanoplatelets
CV	Coefficient of variation
Eq.	Equation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Structure rehabilitation techniques involving repairing or upgrading pipelines systems in civil engineering applications are techniques that commonly used in oil and gas industry. Pipeline in oil and gas industry are being used to transport products such as oil and gas across various soil environment and from offshore to onshore plant. Malaysia has its own pipeline network, the Peninsular Gas Utilization which comprising mainly of gas transmission and supply pipelines and spans over 2500km across peninsular Malaysia (Petronas Gas Berhad, 2017). Most of the pipelines that have been used for transporting products are subjected to various types of damage after long service year (Saeed et al., 2014). The factors that contribute to the pipelines damage includes corrosion, natural forces, construction defect and third parties damaged (Lim et al., 2016). Obviously, pipelines surface that exposed to the water and soil environment will have higher corrosion risk due to active chemical reaction by is surrounding environment (Bernardo et al., 2016). Most of the pipelines that have been operated for long duration that subject to damage needs repair and maintenance to ensure that it can operate smoothly and safely. This is very important for the safety and economy purpose of public and pipeline operators.

Based on previous studies, a few of articles were come out with better solutions for repairing pipeline (Lim et al., 2016; PipeAssure™, 2017). Generally, repairing methods have been developed in order to extend the safety and durability of damaged pipeline. There are two ways to repair pipeline which are conventional steel sleeve and composite repair system (Lim et al., 2016). Conventionally, pipelines are repaired by removing the entire damaged section or using steel sleeve/clamp to reinforce the damaged pipe. The conventional repair method have several disadvantages including safety issues due to hot work, bulky, have limited applications for joints or bends and subjected to corrosion risk in the future. The Clock Spring (2017) show that the composite pipe repairs are stronger than the original pipe, allowing to perform at original Maximum Allowable Operating Pressure (MAOP) and it has been endorsed by peer review and third-party testing in oil and gas industry. The advantages of composite repair system include lightweight, high strength and stiffness, and good corrosion resistance. Even though composite repair systems offer numerous advantages, several issues regarding the performance of the composite repair systems are not fully understood. These issues include conservativeness in existing design codes, effect of defect geometry, and performance and contribution of infill materials. Some of them ignoring the function of the infill materials and mostly focused on the improvement and the performance of the composite wrapping component. They assume that the epoxy grout used is only to fill the void/defect of the damaged pipeline without reinforcement on the pipeline.

1.2 PROBLEM STATEMENT

In general, a composite repair system consists of three mains part: (i) composite wrapper; (ii) adhesive; and (iii) a high compressive infill material. The composite wrapper is used to wrap at the area of repair section. An adhesive is acting as a glue that apply at every single layer of the composite sleeve. Infill materials carry important role of transferring load from pipeline to the composite wrapper and as secondary layer to carry load of the repaired pipe. However, most of previous researches ignoring the function of the infill materials and mostly focused on the improvement and the performance of the composite wrapping component. They assume the function of the epoxy grout is only to fill in the void of the damaged in the pipeline without reinforcement to strengthen the damaged pipe. Since infill is part of the repair component it should somehow contribute in strengthening the damaged section. Therefore, it is hypothesized that by using higher strength infill, it can contribute to overall repair performance.

Numerous researchers have mentioned that the nanofiller system will give the better properties improvement in epoxy grout (Tang et al., 2013; Yue et al., 2014). Since the discovery of graphene nanoplatelets, it have been widely used to improve mechanical properties graphene/epoxy grout (Tang et al., 2013). To achieve enhancement of the mechanical properties of the epoxy, there are several issues need to be addressed, for example, improvement of the dispersion of graphene in resin. This is because, the poor dispersion of the graphene inside the epoxy not only decrease the efficiency but also would cause the graphene slip on each other when force applied on the composite. The good dispersion of graphene will affect the mechanical properties and may enable the extraordinary potential for making advance materials (Yue et al., 2014).

Based on the previous studies, dispersion of nanofillers inside the epoxy resin can be very challenging for researchers (Singhi, 2015). One of the reasons is the low viscosity of resin will cause poorer dispersion of nanofiller. This is one of the reasons why this research needs to be

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